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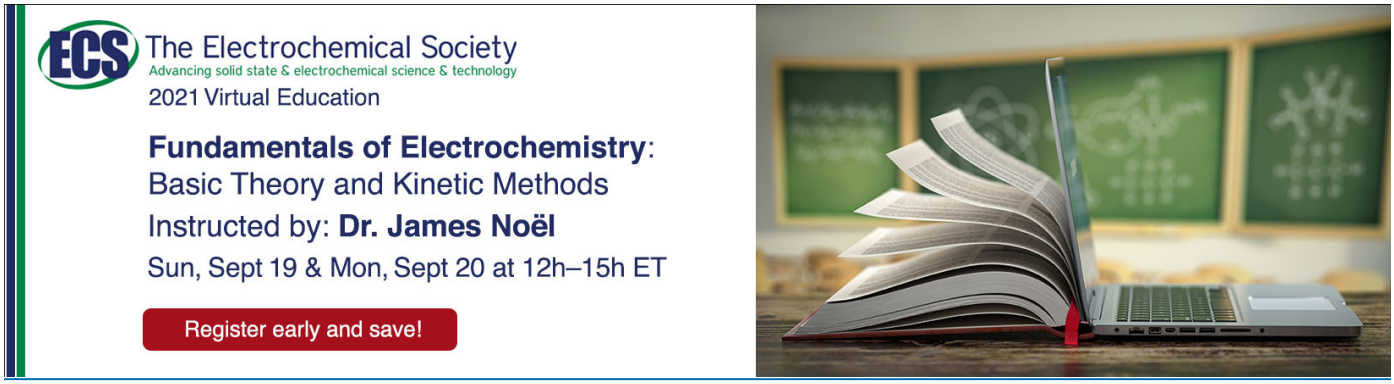

Application of multi-agent approach in the electric power control systems within the active energy complex

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Abstract. This paper provides an analytical overview of artificial intelligence technologies used in the tasks of technological management of the electric power industry. The relevance of using multi-agent systems is proved for solving energy problems. The concept of an intelligent energy system is considered with an active adaptive network (IES AAN). A block diagram of the electric power system management system is given within the IES AAN. It is shown that the developed centralized management principles are not fully applicable for small distribution networks – microgrid, with the use of storage devices and renewable sources. The article describes the active energy complex in Russia in the context of an analog of the Microgrid concept. The required functionality of a intelligent controllable connection (ICC) is studied, the main algorithm of the ICC operation is given, and the proposed structure is described for building a distributed system of intelligent multi-agent control of the AEC that implements the required functions.

1. Overview of the application of intelligent control methods in the energy sector

Currently, researchers in the field of energy engineering note the relevance of smart grid and microgrid technologies in power systems due to the following factors: cheaper distributed generation, the development of microprocessor control systems, and the potential growth of electricity generation using renewable energy sources.[1] The key directions of global development of the world's energy systems are decentralization, decarbonization, and digitalization.[2] Management systems are an important element of future energy systems, using artificial intelligence methods, in particular, multi-agent systems.

A significant number of studies provides evidence of the effectiveness of the use of intelligent control algorithms in the electric power industry. Although some of the approaches are currently being developed, due to significant improvements in measurement systems, computing and communication technologies, there is a significant number of potential applications for real-world electrical networks [3, 4]. There are intelligent control systems built on the basis of multi-agent systems as evidenced by a significant number of works [5, 6, 7, 8, 9, 10].

The paper [9] suggests the use of intelligent algorithms for building emergency automation in large power systems. It is shown that in complex and unstable operating conditions of power transmission lines, the control system successfully performs the specified algorithm of emergency monitoring. The multi-agent software implementation of the control system is performed using Matlab/PSAT in work [9]. It is noted that further investigation of the behavior of a multi-agent system is necessary in

various scenarios. Also, the solution of non-stationary stability problems using the MAS approach has not been developed. [9]

The source [10] provides a systematic description of the multi-agent approach for use in the energy sector. The article represents a justification for the effectiveness of the multi-agent approach since software MAS are well "superimposed" on real objects with a network structure. It is noted that MACS have been used in computer science research for decades, but they are particularly suitable as a basis for creating modern distributed control systems in the energy sector but have not yet found proper application. These requirements become relevant as power systems become more complex and distributed. MAS can bring the greatest effect to management tasks if they allow you to make automatic functions that are traditionally performed by the operator. [10]

In work [11], it is noted that the most promising groups of energy problems where AI can bring an effect are forecasting problems, optimization problems (modes of operation of power system components, consumption, network configuration, etc.), management problems (artificial lighting, renewable energy sources and batteries, asset efficiency, etc.).

Thus, AI methods are widely used in the energy sector.

2. Analysis of an IES AAN approach to the management of networks through intelligent technologies

The unified electric power system (UES) of Russia (former USSR), created more than sixty years ago, is a unique organizational and technical object whose structure and management is built on a hierarchical principle which provided a balanced unity of generation, distribution, and consumption of electricity in the territorial context to ensure the energy security of regions and the possibility of intersystem exchange of power and energy flows in normal and emergency modes.[12]

The Russian energy system consists of 7 interconnected weakly connected United energy systems. In 2010-12, Russia developed the concept of an intelligent EES with the use of an intelligent energy system in an active adaptive network (IES AAN). The IES AAN has created as an analogy to the smart grid concept and provides for the creation of a new technological platform for the UES of Russia. The main directions of management intellectualization in Russian energy systems were developed in 2012 and fixed in the concept of an Intelligent energy system with an active adaptive network (AAN) - similar to the concept of Smart grid adopted in the USA and the EU [13]. Work in Russia on the creation of the IES AAN is carried out at the L. Melentyev Institute of energy systems of the Russian Academy of Sciences [14], JSC "STC FGC UES" [15]. The founders of the direction for creating the IES AAN are: V. E. Fortov, A. S. Makarov, V. V. Dorofeev, Yu.G. Shakaryan, N. I. Voropay, and V. V. Bushuev. The concept defines that one of the main directions of scientific research on the creation of self-healing energy systems is the development of multi-agent intelligent control systems for different levels of the unified energy system. It is argued that artificial intelligence tools which expand the potential capabilities of control systems are relevant and allow you to manage objects with an unknown mathematical model of the object, and increase their efficiency by including image recognition procedures, planning actions, and accumulating knowledge [13]. Figure 1 shows the structure of the centralized management system of the IES AAN proposed in work [13].

The IES AAN is designed for real-time information interaction with a variety of subjects - consumers and generators. Information streams should flow into a single control center which corresponds to a hierarchical structure. The system built on a centralized basis implements technological control actions as well as performs functions for commercial and technical accounting of electric energy, performing tasks of dynamic tariff setting, and managing electricity demand.

With an effective management system, the IES AAN can ensure reliable interaction between network nodes of consumers of various functions and generators, using common principles and a single information technology platform. The main goal of this approach is to introduce intelligent technologies in the Russian energy sector to ensure an innovative breakthrough in the development of this industry and increase the efficiency, reliability, and safety of its operation [1]. The key technologies that were proposed for building a control system are multi – Agent systems, Artificial

neural networks (ANN) and neural network control systems, associative search for identification and management, expert systems, and adaptive real-time modeling platforms.

At the time of its development, IES AAN did not take into account the so-called microgrids that have become widespread in the world by 2020, renewable energy sources, and was also aimed mainly at large, national power systems and backbone networks. In addition, there are currently no generally accepted multi-agent management algorithms in the energy sector that can be applied in Russia despite the stated relevance. Thus, the problem of creating reliable multi-agent control algorithms remains unsolved for a wide class of power systems.

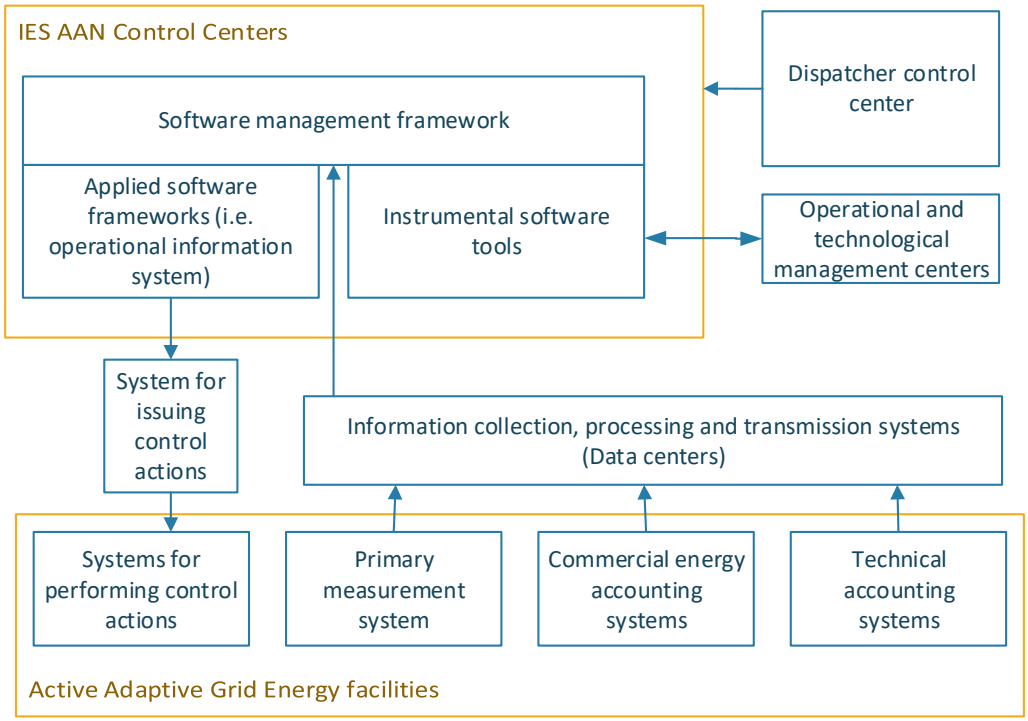

Figure 1. Principal IES AAN centralized control system structure

3. The application of multiagent approach to control the active energy complex

3.1 The active energy complex

The concepts of the IES AAN developed in Russia can be extended and applied in the context of the current development of microgrid ideas in the world's energy systems.

Currently, a decree of the government of the Russian Federation on the organization of active energy complexes has entered into force in Russia. [16] This resolution introduces regulatory opportunities for organizing microgrids for power supply to clusters of industrial enterprises, administrative, business, and shopping centers.

In the context of a pilot project in 2020-2023 in Russia, an active energy complex (AEC) is defined as a microgrid associated with the unified energy system which includes generation with a total capacity of up to 25 MW that does not participate in the wholesale market, and whose consumers are only industrial enterprises, administrative and business centers, and shopping centers. According to [16], AEC are the industrial microgrids created by commercial and industrial consumers and connected to the electric networks of the UES according to a special procedure based on the use of an intelligent controlled connection (hereinafter — ICC). ICC is a key technological element of the AEC which provides continuous monitoring of the flow and metering of electricity (capacity) of the AEC as well as regulates production and consumption in the AEC, including remotely limiting electricity consumption within the permitted capacity of the AEC. The UIS is installed at the point

of connection of the AEC to the public network as well as at generators and consumers that are part of the AEC. [17]

Regulation of energy production and consumption in the AEC, taking into account voluntarily assumed obligations for power consumption from the network (the so — called permitted power), is provided by a managed intelligent connection (ICC) - a hardware and software complex that supports the parameters of power flow from the UES to the AEC within the permitted capacity of the AEC as well as balances energy production and consumption in the AEC and provides the ability to limit the mode of electricity consumption within the AEC. [18] The structure of the active energy complex is shown simplistically in figure 2. Active energy complex is equipped with Controlled intellectual connections (ICC): ICC of the main connection to the external network, ICC of the local generator – ICCg, and user – ICCc. The Algorithm of the basic functioning of the AEC, in accordance with the legislated requirements, is shown in figure 3.

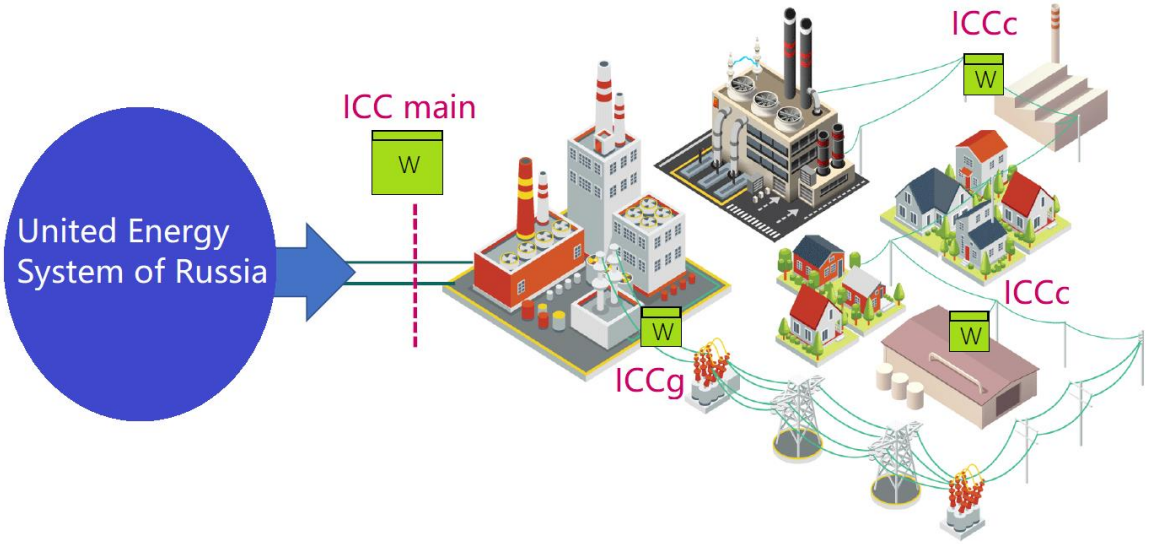

Figure 2. Active energy complex structure

3.2 ICC functionality

A key element of the organization of such complexes is the presence of a centralized intelligent information management system. The tasks that should be solved by such a system were discussed at the legislative level in the Russian Ministry of energy, and the order of the Russian Ministry of energy has not been approved yet – it should be released by the end of 2020. Let's look at some of the functions of the managed intelligent connection of the AEC that are planned for implementation.

The common system functions of ICC include:

1) control of flows between the external and internal microgrid network;
2) automatic regulation of external flows of the active power of the active energy complex with frequency correction by means of automatic regulation of the active power of generating units;
3) automatic allocation of the active energy complex for isolated operation when the frequency decreases;
4) astatic frequency control of the active energy complex;
5) calculation of the volume of services rendered for the transmission of electric energy for each subject of the active energy complex.

The technical and economic functions of the AEC include:

1) Forecast of consumption profiles and prices of the retail electricity market;
2) Optimization of hourly contractual volumes of electricity sales and adjustment of purchase and sale agreements between AEC entities;
3) Economic optimization of loading of generating units;

4) Calculation of the volume of electricity transmission services rendered;
5) Sending certificates of services rendered in electronic form to the network organization and the guaranteeing supplier.

Since the AEC management system is distributed, it is necessary to create a management system architecture that can solve interrelated technological and economic tasks of AEC management in real time. It is proposed to develop distributed control systems using artificial intelligence and MAS methods for solving these problems.

In the Russian practice of energy engineering, there are no control systems, in particular, microgrids, using the intelligent ones considered in this paper. Based on the above, it is promising to develop intelligent systems that have high efficiency for technological management of microgrids and which would simultaneously meet the requirements of Russian legislation, and at the same time embody the best world practices in accordance with the results achieved in science in recent years.

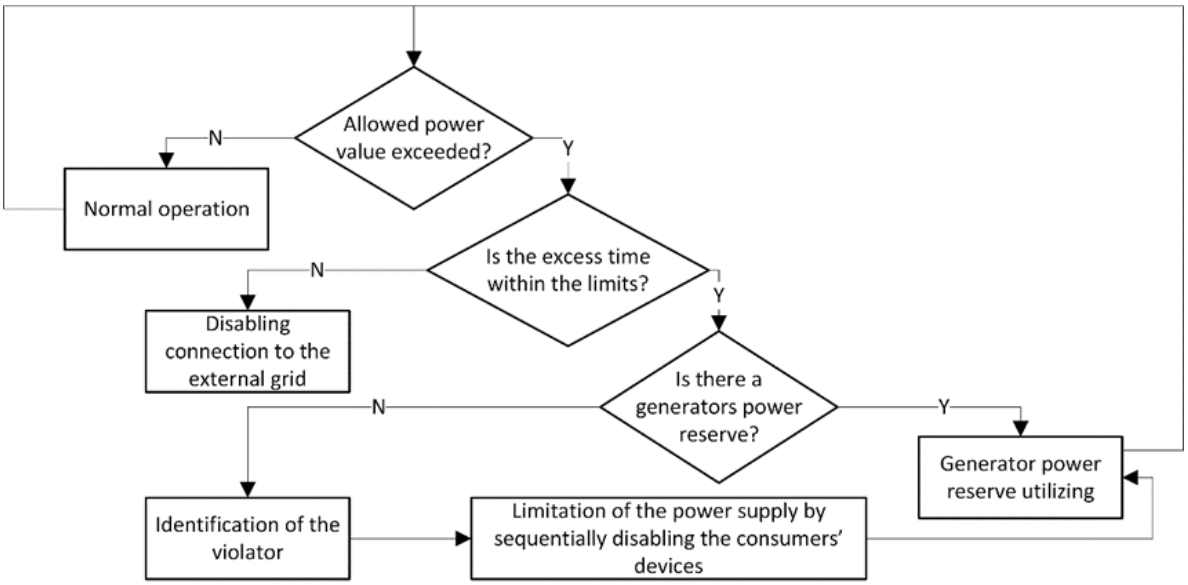

Figure 3. The main operation algorithm of the AEC

3.3 The structure of multi-agent control system

The development of a multi-agent AEC management system is proposed. The expected structure of the MAC is shown in figure 4.

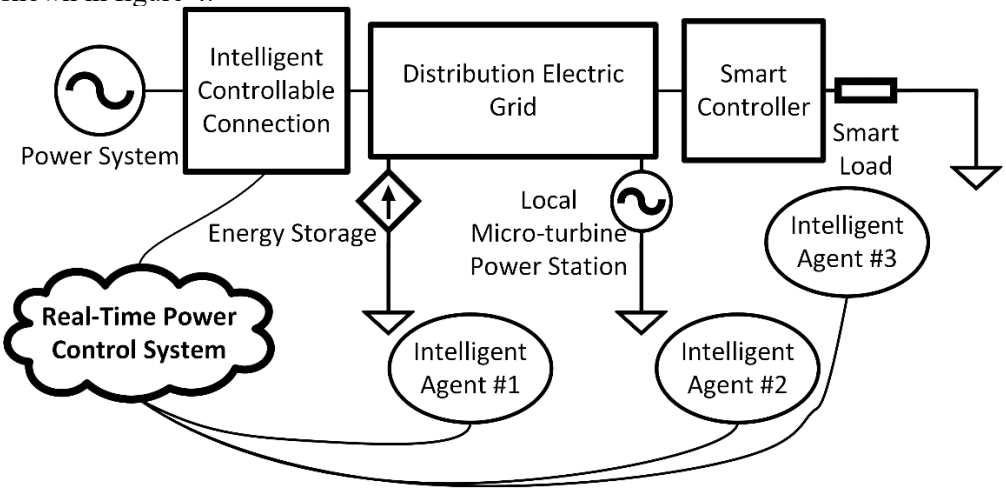

Figure 4. A proposed multi-agent control system structure

In contrast to the IES AAN, this system is decentralized. The structure shows the Central node of the management system – the "cloud management center" as well as the corresponding software agents appropriate to individual subjects of the AEC: generators and consumers. Computing resources should be allocated to individual agents. It is assumed that each intelligent agent is implemented on its own computer and provides calculations in part of the "own" object of the physical system. Intelligent control algorithms are expected to be created in the future.

One of the required functions of the ICC AEC is to perform real-time optimization of the load of generating units in accordance with the operating mode of power receiving devices of consumers. This function can be solved on the basis of currently developed intelligent management methods in the field of micro-cities.

Conclusion

This paper analyzes the relevance of the use of intelligent control methods in the energy sector. It is established that the use of MAC is actual, basing on numerous sources. It is shown that the concept of the IES AAN created in Russia does not fully take into account modern legislation regarding the construction of microgrids (AEC) in Russia, and therefore it is necessary to create intelligent control systems that can effectively solve emerging tasks. In Russian practice, there are no multi-agent control systems that are suitable for solving problems of managing active energy complexes. A block diagram of an intelligent control system for working in the AEC is proposed, basing on a multi-agent approach. The requirement is given for the functionality of the control system. The further direction of research development is the engineering of algorithms for the functioning of individual agents, the creation of appropriate software.

Acknowledgments

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